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SHIP ROLL STABILIZATION AND HUMAN PERFORMANCE

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to assess possible performance enhancements due to roll stabilization. Psychomotor performance was assessed under no motion, roll stabilized, and non-roll stabilized motion conditions in the Naval Biodynamics Laboratory Ship Motion Simulator. Twelve human research volunteers participated as subjects in the study. The motion conditions were measured and recorded at sea aboard an FFG-7 class frigate outfitted with five roll stabilizers. The following performance tests were used: four-choice reaction time; memory and search task; critical instability tracking. Three questionnaires were used, namely motion sickness symptomatology, magnitude estimate of motion sickness, and magnitude estimate of motion. It was found that subject performance was not affected by roll stabilized motion compared to non-roll stabilized motion in these experimental conditions. Subjects accurately judged the non-roll stabilized motion condition to be greater than the roll stabilized condition, but reported no differences in motion sickness in the two conditions.

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INTRODUCTION

Numerous studies have reported that whole body motion degrades various types of human performance. McLeod et al. [1] found two types of tracking performance to be degraded under motion conditions. The investigators used a motion simulator driven in heave, pitch, and roll motions by signals recorded from a frigate at sea (the HMS *Avenger*), and subjects performed pursuit-tracking tasks with either a pressure stick or a free-moving control stick. In these experiments, wrist support was allowed during the tasks and motion with the following characteristics was used: Peak-to-peak vertical motion was 2.5 m; vertical acceleration was 0.024 g; heave frequency was between 0.1 and 0.3 Hz; and little pitch and roll motion were included. In another study Jex et al. [2] used a three-degree-of-freedom motion generator and found that motion conditions of 0.2 to 2.0 Hz at 0.5 to 1.0 g produced biodynamic interference with motor tasks (navigational plotting, writing, and critical tracking).

Wiker et al. [3] presented results from an earlier study (Wiker and Pepper, 1978) that investigated a variety of performance measures, both dockside and at sea, aboard a 95-ft Coast Guard patrol boat. Significant performance decrements were obtained in navigational plotting accuracy and visual search performance in a letter search task while at sea. Wiker et al. [3] investigated the effects of vessel size and hull design on performance, physiology, and mood during three days each of steaming aboard a 95-ft patrol boat, an 89-ft Small Waterplane Area Twin Hull (SWATH) vessel, and a 378-ft Coast Guard cutter. At-sea performance in all nine performance measures, based on a battery of six different tests, was significantly degraded in the patrol boat. The six tests were: code substitution, complex counting, critical tracking, navigational plotting, Spoke Test, and time estimation.

Fin roll stabilization and rudder roll stabilization systems provide effective ways to reduce ship roll. Basically, a fin roll stabilization system consists of accelerometers that provide input to a servo system. When roll acceleration is sensed, the servo system varies the pitch of submerged fins attached via shafts near the middle of the ship. Since roll acceleration precedes roll displacement, and given the slow response time of ship displacement, the fin roll stabilization system input sufficiently precedes displacement so that roll motion can be predicted and greatly reduced by fin pitch changes made before the roll occurs. Rudder roll stabilization systems have a similar accelerometer servo system. However, their output activates changes in rudder movement to reduce roll. Although the patent for stabilizer fins was granted to John I. Thornycroft in 1889, the first successful application was on the British ship S.S. *Isle of Sark* in 1935. The U.S. Navy installed stabilizer fins on the USS *Gyatt* (DDG-712) in about 1956; subsequently, many U.S. Navy ships have been successfully equipped with stabilizer fins [4]. The development and application of rudder roll stabilization (RRS) systems is more recent. The first generation analog control RRS, introduced in 1977, produced a 30 to 40% reduction in roll motion using the ship's existing rudder steering system. In 1987 a second generation digital control RRS was introduced that achieved a reduction of up to 70% less roll motion [5].

Roll stabilization produces numerous advantages. Pitching and slamming may be minimized by taking the sea on the beam — a heading that might be unacceptable without roll reduction. Roll reduction directly benefits helicopter operations, underway vertical replenishments, connected replenishments, combat system functions, sonar and radar capabilities, and maintenance and repair tasks [4]. With the increased combatant capabilities of helicopters, major research and development efforts have been directed toward the ship/aircraft interface [6]. The ship/aircraft interface is strongly dependent on weather and ship motion. Baitis et al. [6] provided evidence that RRS use produced significant improvements in helicopter launch and recovery operations and reductions in motion-induced interruptions in operator tasks and in motion-induced fatigue. The above studies indicate that: (a) motion can degrade various types of human performance, and (b) reducing ship roll with stabilization systems produces many practical benefits.

The purpose of the present study was to assess possible performance enhancements due to roll stabilization. The present study assessed psychomotor performance in a ship simulator under conditions of no motion, roll stabilized motion, and non-stabilizated motion.

METHOD

SUBJECTS

Twelve Human Research Volunteers (HRVs) participated as subjects in this study. They were junior enlisted Navy males who had been rigorously screened, medically and psychologically, for full-time duty assignment as subjects for biodynamic research at the Naval Biodynamics Laboratory (NAVBIODYNLAB). Their mean age was 21.8 years; range was 20.1 to 26.5 years. The HRVs were randomly assigned to two equal groups, with the constraint that the groups were matched in terms of scores on a motion sickness susceptibility questionnaire.

APPARATUS

Performance Testing Equipment

The performance testing equipment was that prescribed for use with the Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB) [7]. The hardware consisted of a Zenith Z-248 computer with a 16-bit 80286 processor, clock speed of 8.0 MHz, and 80287 math co-processor. The Z-248 was equipped with a Sigma Designs Color 400-SH board and a Systems Research Laboratory SRL-Labpac Multi-function Board. The Stimulus Equipment Company's Mini-Modulus III is a standardized subject response panel produced specifically for the UTC-PAB. This panel contained three interchangeable modules: a tapping key, a 180° resistive (proportional output) joystick, and a numeric keypad on which one key was labeled "S" and another "D." Two response panel configurations were used: The right-handed version had the numeric keypad on the right, joystick in center, and tapper switch on the left; for the left-handed version, the keypad and tapper were reversed. The tests and questionnaires were presented on a Princeton Graphic Systems SR-12 RGB color monitor.

Two identically configured test stations were used. One was instrumented in the

NAVBIODYNLAB Ship Motion Simulator (SMS), the other in the Static Cab, a fixed-base replica of the SMS. The two test stations and the experimenter control station were connected via a NESTAR PLAN-4000 local area networking (LAN) system. The NESTAR system included two 140 MB hard disks for on-line data storage and for maintenance of the test programs. The LAN configuration allowed subjects to be tested simultaneously in the Ship Motion Simulator and the Static Cab. The testing sessions were monitored and controlled at the experimenter's station.

NAVBIODYNLAB Ship Motion Simulator (SMS)

The SMS is a facility which provides the capability of moving an 8-ft (2.5-m) cubical cab in heave, pitch, and roll motions. A photograph of the SMS facility is presented in Figure 1. Figure 2 depicts the major components — the cab, carriage, and vertical tower — and illustrates the range of motion. The SMS is driven by a hydraulically powered piston, the motion of which is controlled by modulating the hydraulic flow via a servo-valve-controlled actuator. The moving system, consisting of the cab and the carriage, is guided by the adjacent rail-and-roller tower (which is not load-bearing). It carries a double yoke-and-trunnion system, operated under similar but independent control, that permits roll and pitch motions to be superimposed, singly or in combination, upon the vertical translational ("heave") oscillation. The hydraulic power is delivered by combinations of up to four drive pumps located in a separate building.

The performance envelopes of the SMS are summarized in Table 1. The descent of the carriage during the heave downstroke is gravitational, and accordingly limited in practice to approximately 0.9 g. In the event of failure of electrohydraulic control or the imposition of an excessive vertical drive signal with failure of electrical sensors, mechanical buffers stop the carriage motion with a deceleration not exceeding a 5 g spike. The SMS can accommodate a total payload of 5000 pounds (2270 kg), including the Moving Cab and up to three human test subjects.

The entire SMS system was designed with numerous multi-level safety interlocks and has been evaluated and approved for human use by an independent Man Rating Safety Review Committee. All SMS research protocols were reviewed and approved by a Committee for the Protection of Human Subjects.

The SMS Motion Cab (Figure 3) is an 8-ft (2.5-m) cube with the forward top edge truncated to accommodate forward pitch motion adjacent to the tower. In its standard configuration, the air-conditioned Motion Cab is windowless (although view ports can be fitted in other configurations). Subjects are continuously observed at the control station by means of closed-circuit TV; two-way communication is conducted with an audio system. Electrical power, communications, and low-voltage electronic data to and from the Motion Cab are conveyed by screened and protected trailing cables.

The Motion Cab can be fitted with up to three forward-facing seats (with the manufacturer's military helicopter type safety harnesses installed) and with parallel, facing bench-type workstations equipped with video display terminals (VDTs) and other performance testing apparatus. In the present study, each subject was tested in the port seat. The Modulus response panel was attached with velcro to the top surface of the workstation, directly in front of the test subject. A Princeton SR-12 VDT was used. A large push-operated abort switch, with which the test subject could stop the experiment at any time, was readily accessible from each seat. The cab is also equipped to provide biomedical monitoring capabilities.

The SMS is supported by an AST/286 microcomputer and a Hewlett-Packard 6942A Microprogrammer. Selected motion data are loaded via the microcomputer into the 6942A, which then functions as a stand-alone device, converting the digital data into the analog format required to drive the SMS. The microcomputer is also used for digitization, storage, and subsequent analysis of motion and/or other data from the SMS. A dedicated 14-channel, proportional-bandwidth FM analog tape recorder is also available for data collection and/or playback into the SMS. Sinusoidal or arbitrary synthetic drive signals can be generated via three dedicated Hewlett-Packard 3314 Arbitrary Function Generators.

TABLE 1: SHIP MOTION SIMULATOR PERFORMANCE CAPABILITIES

HEAVE	
Displacement	±11 ft (3.5 m)
Velocity	±17 ft (5 m) per second
Acceleration	+2.0 g(z) to −0.92 g(z)
Usable Bandwidth	0.03 to 2 Hz
PITCH AND ROLL	
Displacement	±15°
Rate	±25° per second
Acceleration	±150° per second per second
Usable Bandwidth	0.06 to 3.0 Hz

Static Cab

The Static Cab is a fixed-base dimensional replica of the Motion Cab. Its test station is identical in equipment and configuration. The interiors of both have been carefully matched in terms of painting (a light, flat gray), lighting, air-conditioning, experimental equipment, and other relevant variables. The Static Cab is used for baseline training prior to testing in the SMS.

PROCEDURES

Test Battery

The performance tests used included the Walter Reed Army Institute of Research Performance Assessment Battery (WRAIR-PAB) four-choice reaction time test, memory and search tasks [8], and the System Research Laboratory version of the critical tracking task [9]. These performance tests are included in the UTC-PAB and have been described in great

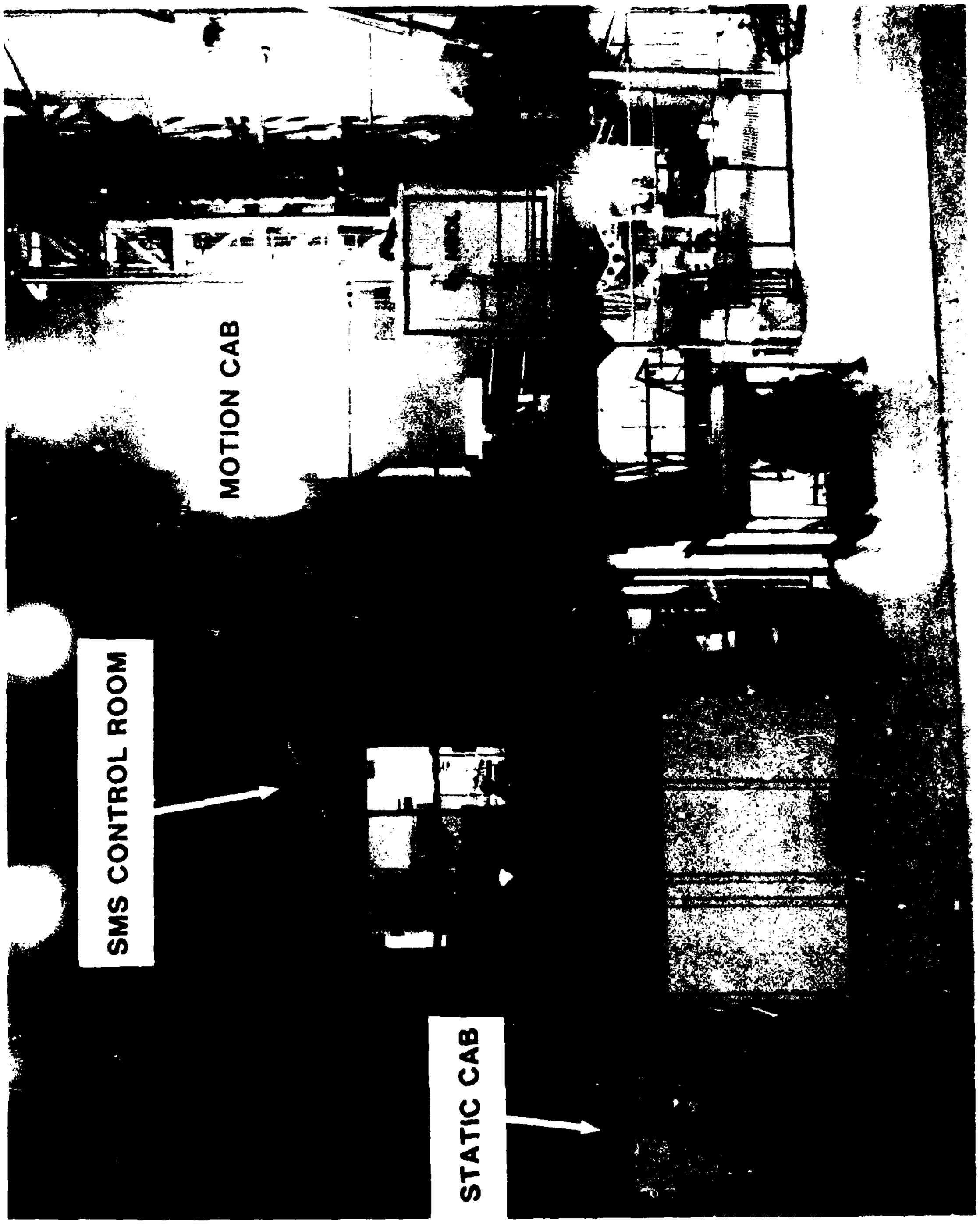

Figure 1. Naval Biodynamics Laboratory Ship Motion Simulator Facility.

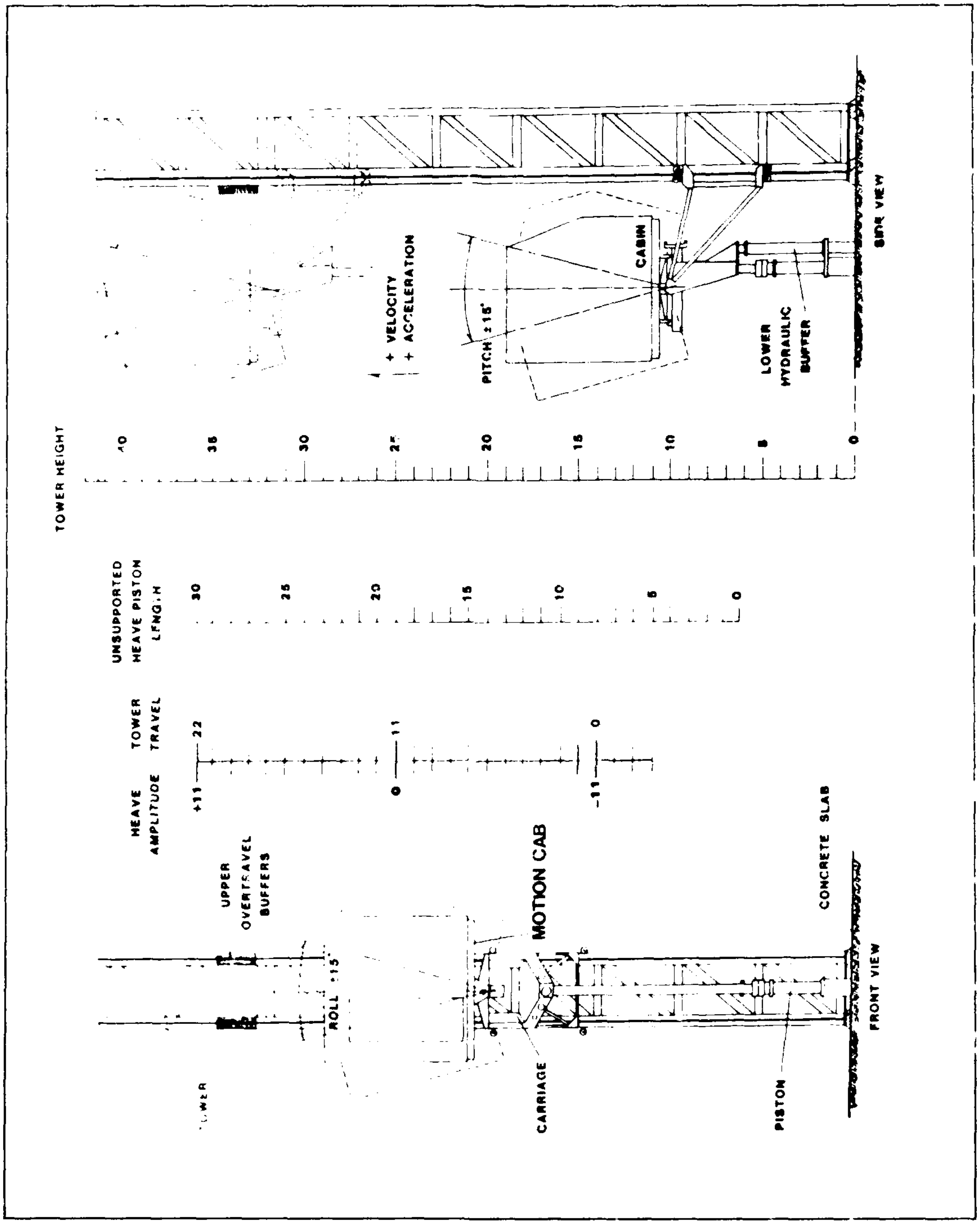

Figure 2. Naval Biodynamics Laboratory Ship Motion Simulator Range of Motion.

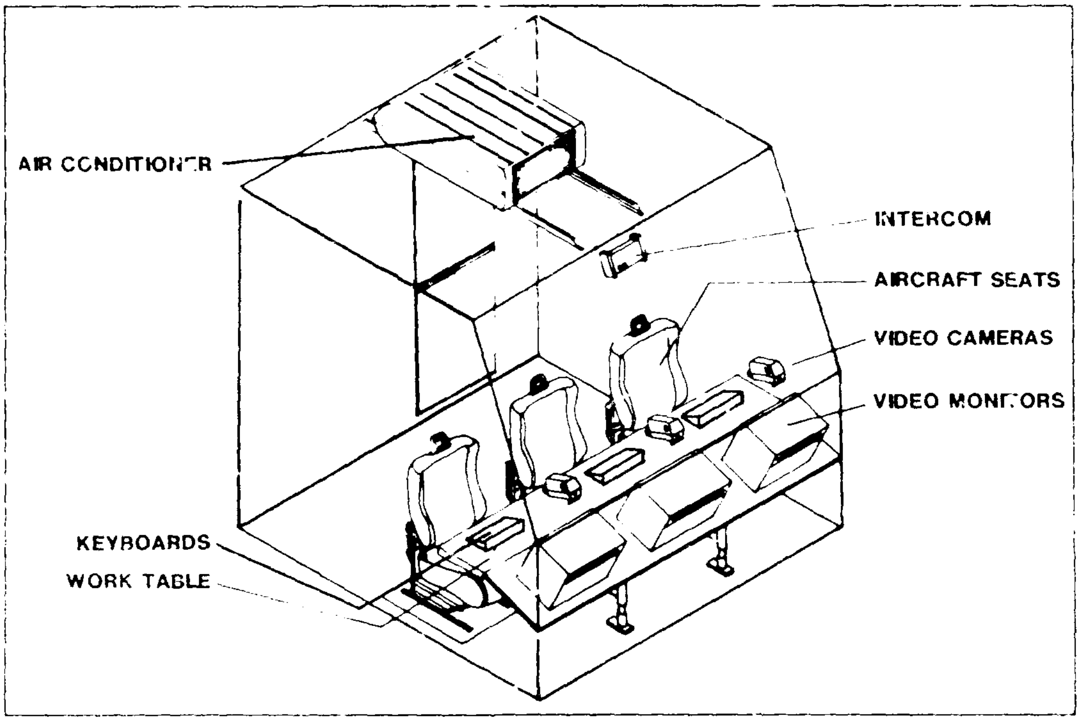

Figure 3. Naval Biodynamics Laboratory Ship Motion Simulator Motion Cab.

detail elsewhere [10, 11]. The test battery also included a motion sickness checklist, motion magnitude estimation, and a motion sickness estimation questionnaire, all of which were developed at the NAVBIODYNLAB. The time required to complete the test battery once was approximately 11 min.

Four-Choice Reaction Time Task. This task is a modification of the four-choice reaction time task developed by Wilkinson and Houghton [12]. During the task a plus sign ("+") appeared in one of four quadrants of the monitor screen. The subject was instructed to press the key (one of four) on the keypad that spatially corresponded to the screen quadrant in which the plus sign appeared. The plus sign remained visible until the subject pressed one of the four keys. Immediately after the key press, the plus sign randomly reappeared in one of the four quadrants. Subjects were instructed to respond as quickly and accurately as possible. Each test interval consisted of 65 stimulus trials, or 180 sec, whichever came first.

Memory and Search Task. Two target letters were presented at the top of the monitor screen; simultaneously a row of 20 letters appeared in the middle of the screen. The task was to determine whether both target letters were present in the row of 20 letters. If both target letters were present, in any order, the subject was instructed to press the "S" (for "same") key on the keypad. If both letters were not present, the subject was instructed to press the "D" (for "different") key. Both the target and search row letters changed with each trial. Subjects were instructed to respond as quickly and accurately as possible. Each test interval consisted of 32 stimulus trials, or 180 sec, whichever came first.

Critical Instability Tracking Task. The software for this task was produced by the System Research Laboratory (SRL) for use by UTC-PAB participating laboratories. The task display consisted of a stationary horizontal white line with vertical "walls" at each end, a red triangle centered below the line, and an inverted white triangle above the line. A trial started when the white triangle moved horizontally either right or left from center. The task was to keep the white triangle cursor centered over the stationary red triangle by manipulating the joystick. The instability of the task was activated by the subject's movement of the joystick and a predetermined initial error value. When the subject attempted to maintain the centered position, the error (i.e., the number of degrees the cursor is off center) was recorded, transformed, and then added back into the system to increase the movement of the cursor. When the cursor hit either wall, it automatically reset to the center position and after 1 sec began to move again. The performance scores were root mean square error of cursor deviations from center, number of wall hits, and final Lambda value. Lambda is a task difficulty index, in that the cursor deviation from center is multiplied by the Lambda value to determine the next cursor position. In the tracking task defined in this experiment, the initial low Lambda was set at 2.0; the high Lambda was set at 10.0. The task duration was 4 min. The Lambda increment is a function of the low and high Lambda settings and the task duration. The Lambda decreased by 3% following each wall strike.

Motion Sickness Symptomatology Questionnaire. The motion sickness questionnaire is a checklist consisting of 24 word or phrase descriptions of motion sickness symptoms, e.g., dizziness, stomach awareness, nausea, headache. Each symptom was presented individually and the subject was instructed to rate it from 0 to 3, according to how often he had felt that way.

Motion Sickness Magnitude Estimation. The subject was instructed to indicate on a scale of 0 to 9 an overall rating of his feelings and symptoms of motion sickness.

Motion Magnitude Estimation. The subject was instructed to estimate, from 0 to 9, the amount of motion he presently perceived.

Motion Conditions

The non-roll stabilized (NRS) and roll stabilized (RS) conditions were measured and recorded at sea aboard the USS *Rentz*, an FFG-7 class frigate outfitted with 6 roll stabilizer fins. From the recorded data, two segments (approximately 10 min for RS, 12 min for NRS) were selected, one in which the stabilizers were in use; the other in which the stabilizers were not. These data, collected in digital format, were input to the NAVBIODYNLAB SMS. The extensive and exacting NAVBIODYNLAB SMS calibration procedure was performed and documented by Willems [13]. NRS and RS had similar pitch (displacement ±2.5°), g levels (less than 0.1 g), and dominant range of frequencies (0.06 to 0.2 Hz). NRS heave range was 12.5 ft (3.83 m); RS was 10.0 ft (3.06 m). NRS roll displacement was ±11.5°; RS was ±5°. NRS roll rate was ±6°/sec; RS was ±4°/sec. During each SMS experimental motion run the RS (or NRS) motion segment "repeated" itself to fill up the one hour motion test session. The "wrap-around" point for the two motion segments' "patch" was carefully selected to produce smooth, continuous motion.

Test Protocol

The test protocol per subject lasted three weeks. Week 1 consisted of four days of baseline training administered in the Static Cab. Subjects were tested for approximately 70 min each day, during which they performed the battery six times. Short breaks were allowed during the test session between battery presentations. During Week 2, Days 1 and 4, the subject performed the test battery six times daily in the SMS while the SMS was deactivated, i.e., with no motion. These sessions were designed to allow the subject to adapt to the SMS under static conditions. Thus, each subject performed a total of six baseline training sessions, four (B-1, B-2, B-3, and B-4) in the Static Cab and two (B-5 and B-6) in the Motion Cab (static).

During Week 2, Days 2 and 3, the subjects experienced a 10-min SMS motion-orientation ride. During these runs, half the subjects received RS on Day 2 and NRS on Day 3; for the other subjects the order was reversed. Week 3 consisted of two days of motion testing in the SMS under each motion condition. Group RS-NRS received the motion conditions in the following order: RS, NRS, RS, and NRS on Days 1, 2, 3, and 4, respectively. Group NRS-RS received the motion conditions in the opposite order. Each SMS ride lasted 60 min, followed by a post-motion test session to evaluate recovery from motion. This began with administration of the Motion Sickness Questionnaire, followed by two completions of the test battery. Each post-motion test session lasted approximately 23 min.

Testing start times were 0800, 0945, 1230, and 1415; each subject was tested at the same time of day throughout his three weeks. Subjects were fitted with skin electrodes for continuous heart rate monitoring.

RESULTS

ANALYSIS

Some data loss occurred for a few subjects during various conditions. In order to maintain as large an *N* as possible, not all test conditions were included in the analyses. Repeated measures analyses of variance (ANOVAs) were performed for each dependent measure. Motion was the within-subject variable. The six levels of Motion included in the ANOVAs were: (1) Baseline (Static Cab) Day 3 (B-3); (2) Baseline (SMS static) Day 5 (B-5); (3) the first NRS presentation; (4) NRS-Post (static); (5) the first RS presentation; and (6) RS-Post (static). Thus data for the second exposure to each motion condition were not included in the analyses. During Week 3, Group RS-NRS received RS and RS-Post on Day 1, NRS and NRS-Post on Day 2; Group NRS-RS received the opposite order of motion condition presentation. For analysis purposes, Group RS-NRS included five subjects; Group NRS-RS, six. One subject's data were excluded from the analysis because of outlier characteristics. Probability (p) values reported for the various F-tests used in the ANOVAs were Greenhouse-Geisser probability values.

Critical Instability Tracking Task

Final Lambda. Lambda was a measure of difficulty that progressively increased as the tracking task progressed. When a "wall hit" occurred, the Lambda decreased by 3% on the following task presentation. Final Lambda was the terminal Lambda value achieved during the 4-min testing session. Figure 4 presents average final Lambda data for the two groups of subjects. The ANOVA results indicated no significant Motion, Order, or Motion by Order interaction effects. Figure 4 suggests that tracking performance was still improving after subjects received five training sessions per day for four days.

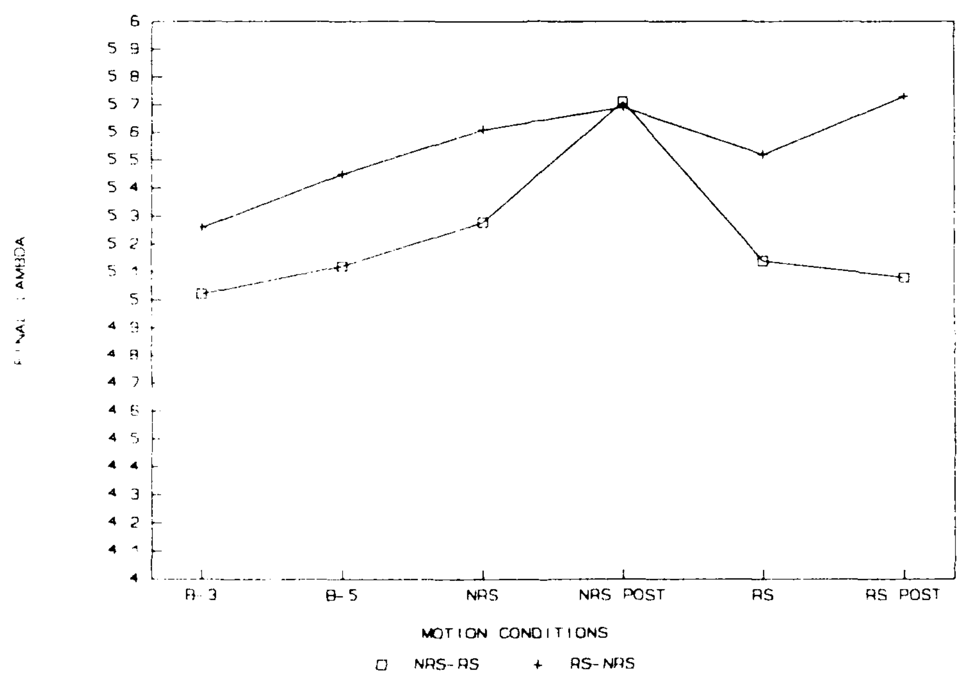

Figure 4. Critical tracking mean final Lambda scores as a function of the motion conditions.

Root Mean Square (RMS) Error. The critical tracking mean RMS error scores are presented in Figure 5. The ANOVA results indicated no significant Motion, Order, or Motion by Order interaction effects.

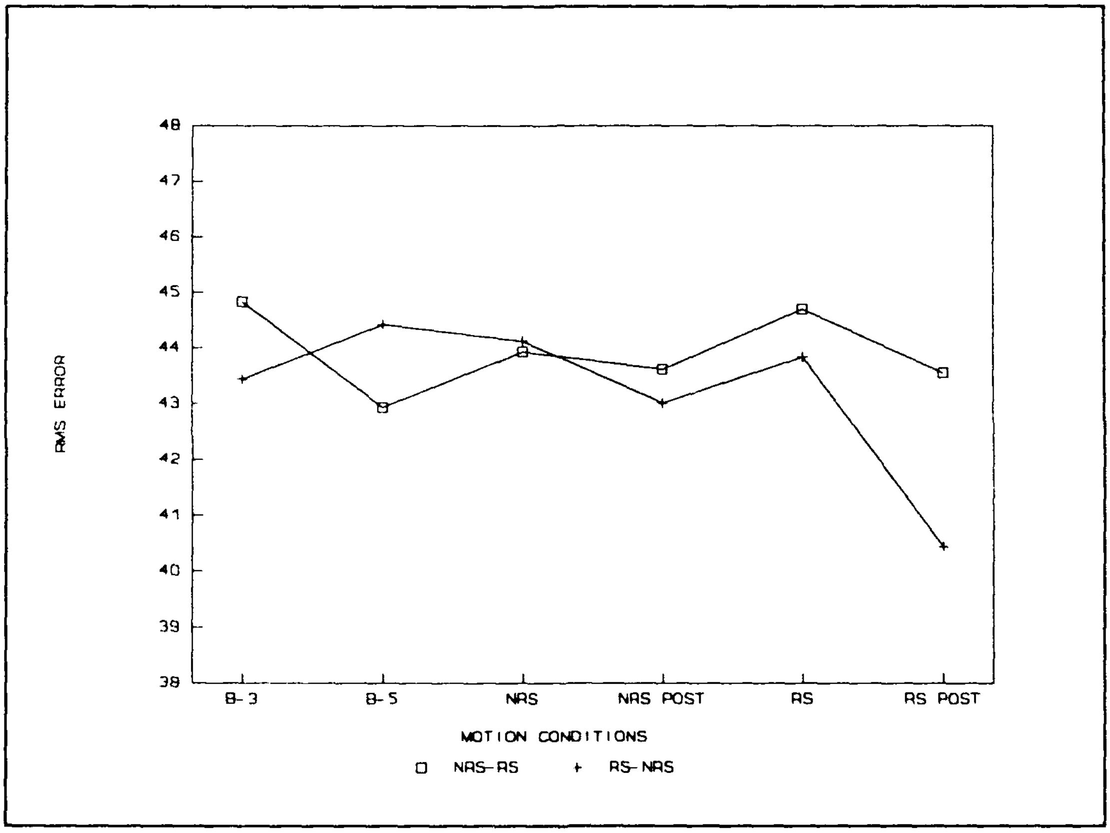

Figure 5. Critical tracking mean RMS error as a function of the motion conditions.

Wall Hits. Critical tracking mean wall hits are presented in Figure 6. The ANOVA results indicated that Motion effects approached significance, $F(5, 45) = 2.60, p = .08$. Neither Order nor Order by Motion interaction produced significant effects.

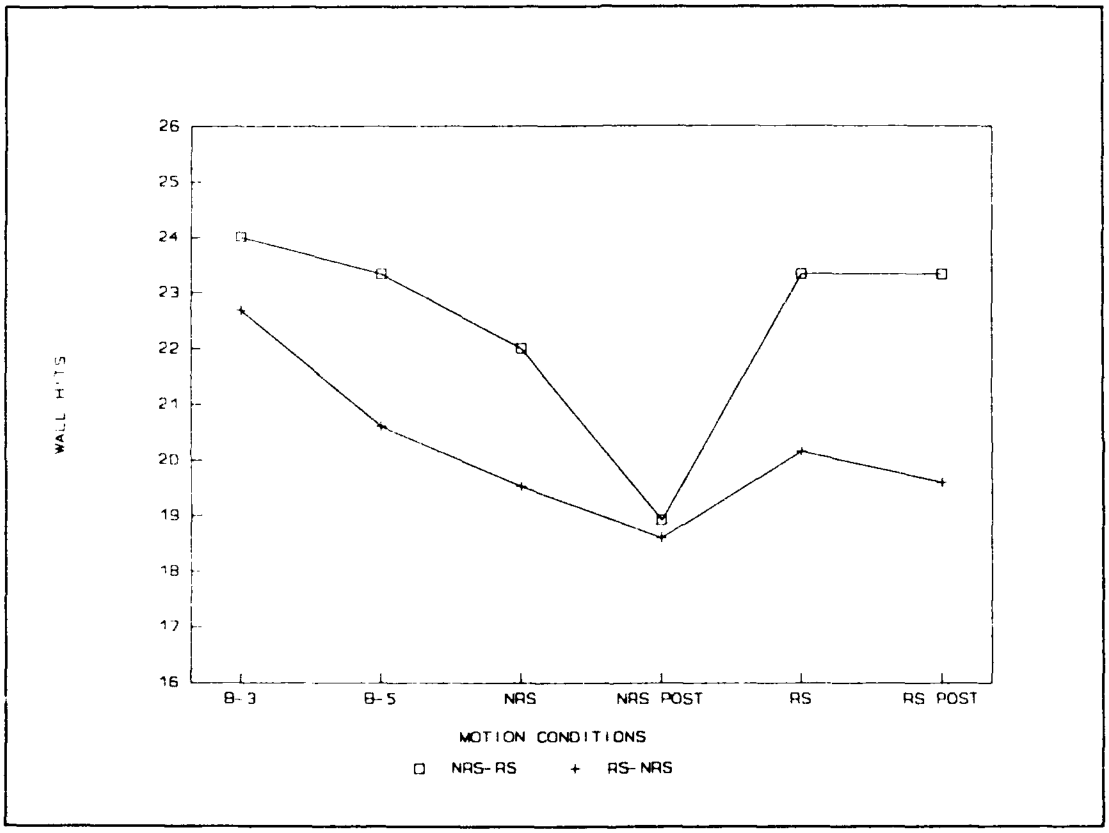

Figure 6. Critical tracking mean number of wall hits as a function of the motion conditions.

Memory and Search Task

Percent Correct. Figure 7 presents percent correct scores. No Motion or Motion by Order interaction were obtained. Order approached significance, $F(1, 9) = 3.07$, $p = .11$. As shown in Figure 7, the near significant Order effect is due to differences between the two groups. Group RS-NRS performed at a higher mean accuracy at Baseline Test Day 3 and maintained this greater level of accuracy during the other conditions.

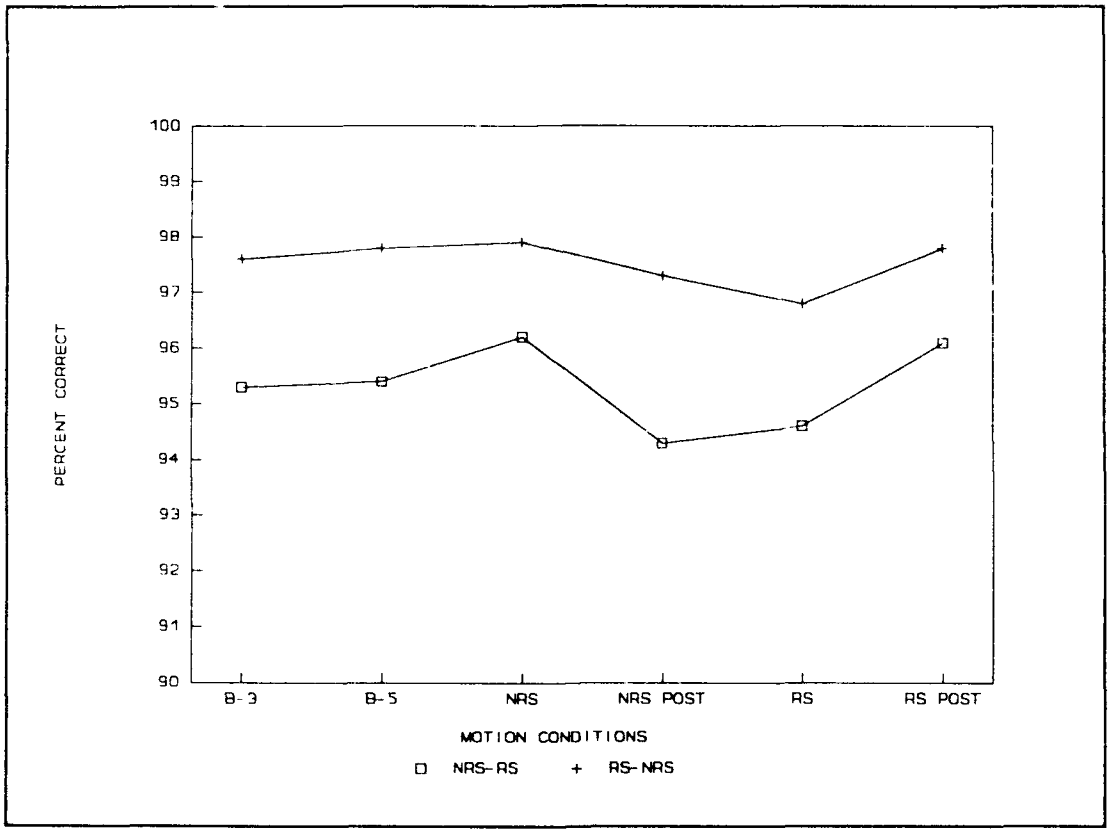

Figure 7. Memory and search task mean percent correct scores as a function of the motion conditions.

Response Times. The memory and search task response times are presented in Figure 8. The ANOVA results found no significant effects due to Motion, Order, or Motion by Order interaction.

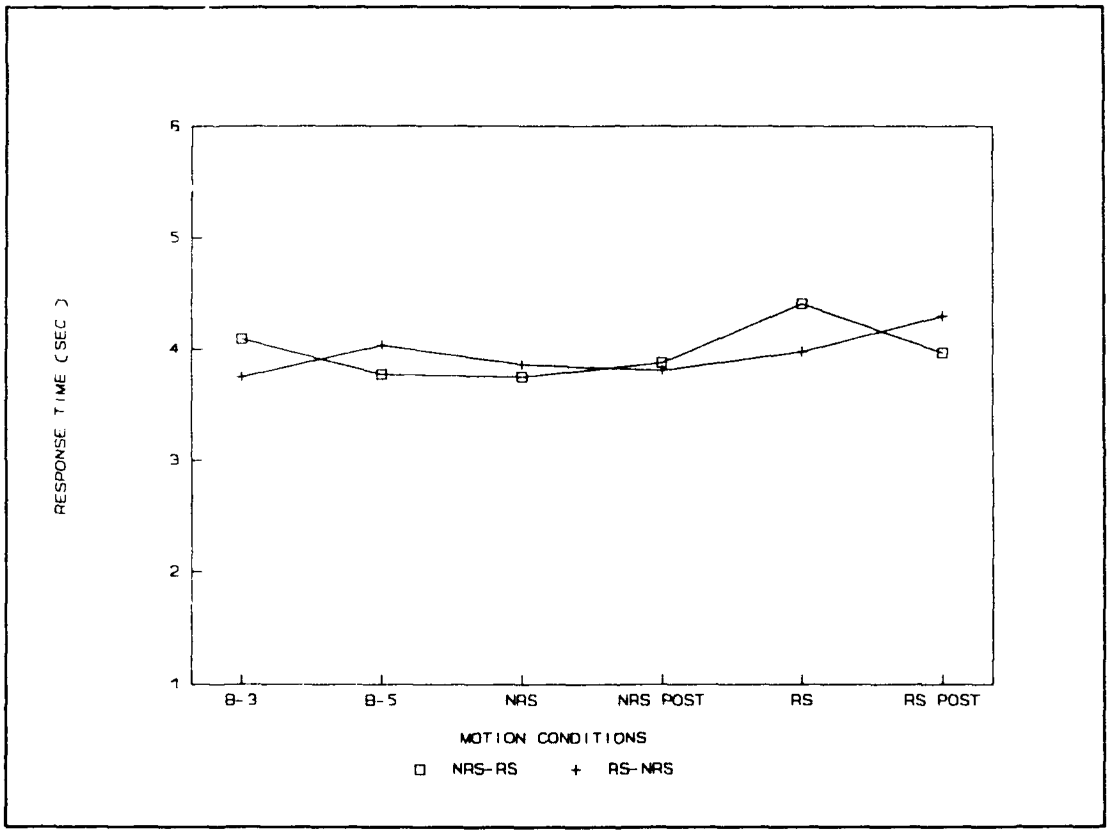

Figure 8. Memory and search task mean response times as a function of the motion conditions.

Four-Choice Reaction Time

Percent Correct. The range of mean percent correct scores among the two groups by six motion conditions was 98.11–99.99, indicating that the subjects performed at a consistently high level of accuracy for all conditions during this task.

Reaction Time. The four-choice mean reaction times are presented in Figure 9. No significant Motion, Order, or Motion by Order interaction effects were obtained.

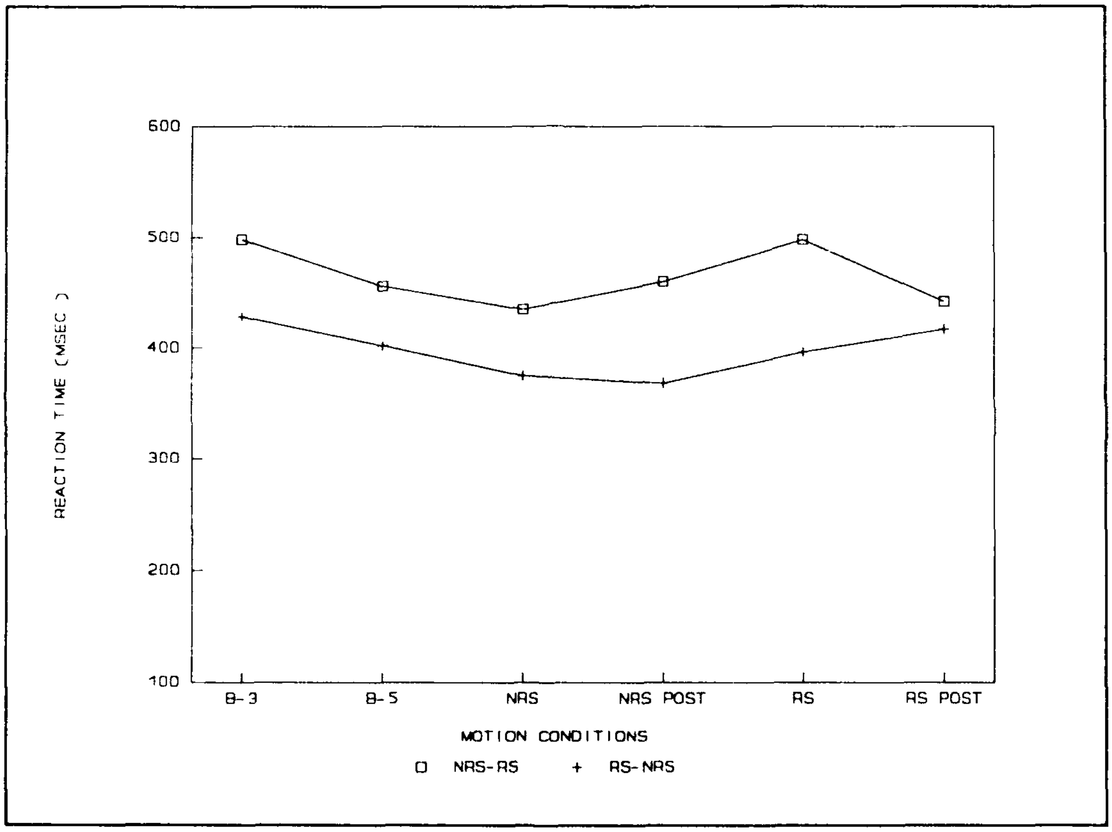

Figure 9. Four-choice mean reaction times as a function of the motion conditions.

Symptomatology

The mean symptomatology checklist data are presented in Figure 10. The means were computed from weighted response scores. That is, there were 24 symptomatology descriptions presented, to which subjects responded with either 0, 1, 2, or 3. The sum of the subject's response scores for all 24 symptomatology descriptions comprised the weighted symptomatology score. Mean weighted scores were entered into the ANOVA. The ANOVA results indicated no Motion, Order, or Motion by Order interaction effects.

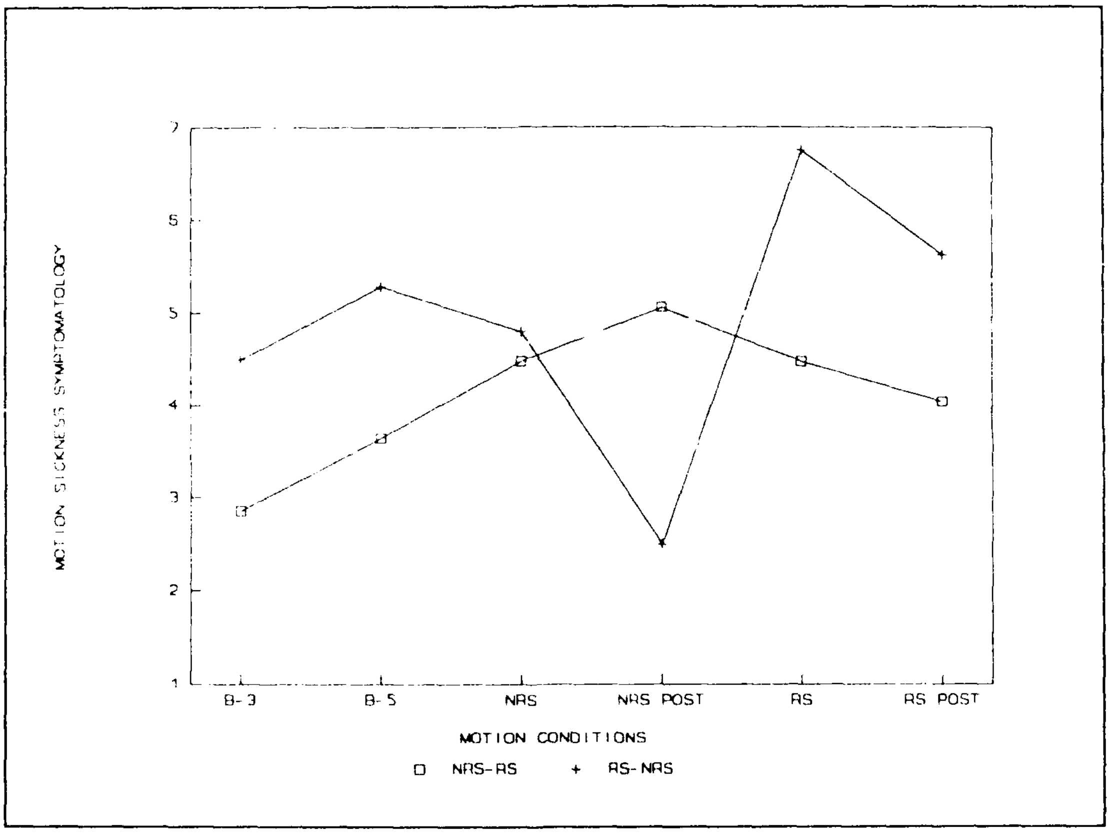

Figure 10. Mean motion sickness symptomatology scores as a function of the motion conditions.

Motion Magnitude Estimation

The mean motion estimates are presented in Figure 11. The ANOVA results indicated a significant Motion effect, $F\,(5, 40) = 36.87$, $p < .0001$. The Duncan Multiple-Range Test was used to make *post hoc* mean comparisons. Subjects judged NRS motion to be greater than RS; RS motion was judged greater than NRS-Post (static) and RS-Post (static) motion, which were judged greater than motion (actually no motion) during Baseline Test Days 3 and 5. No Order or Motion by Order interaction effects were obtained.

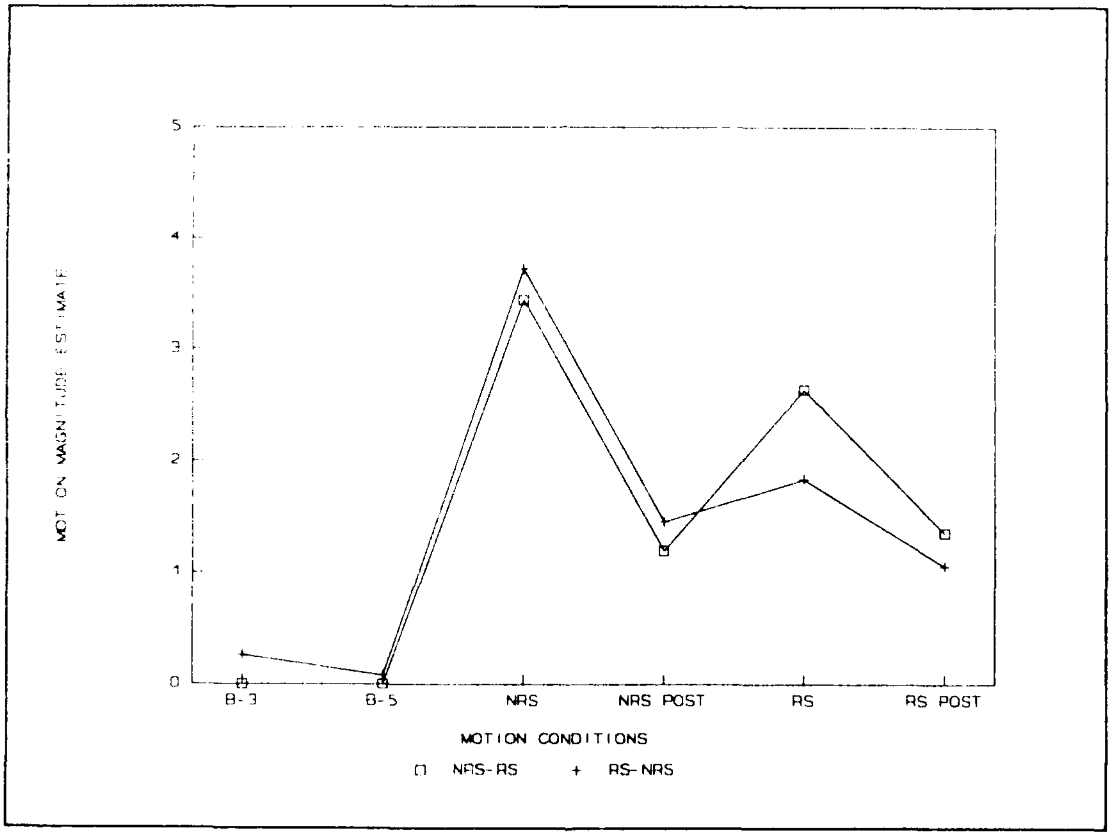

Figure 11. Mean motion magnitude estimates as a function of the motion conditions.

Motion Sickness Magnitude Estimation

The mean motion sickness estimates are presented in Figure 12. No significant effects due to either Motion, Order, or Motion by Order interaction were obtained. Although the means for Group RS-NRS were higher during the two motion and post-motion conditions, the mean differences were not significant.

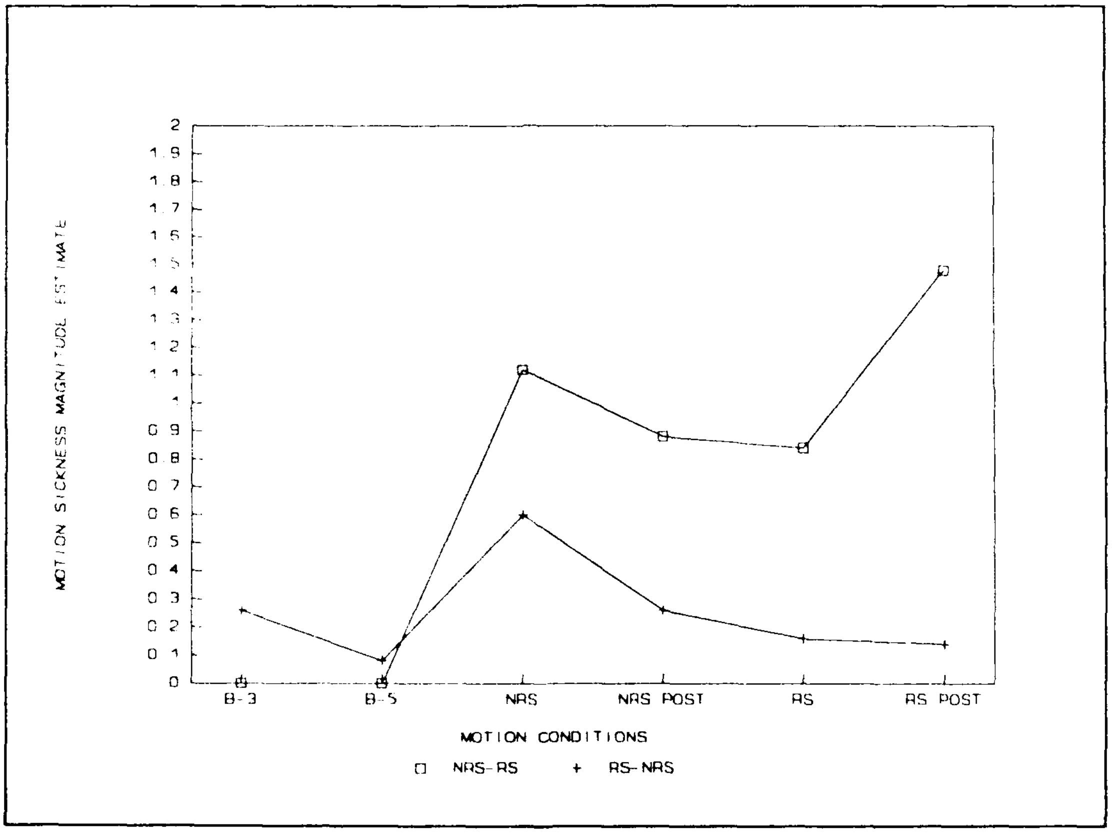

Figure 12. Mean motion sickness estimates as a function of the motion conditions.

DISCUSSION

The subjects' lack of performance differences between the motion and static conditions was clearly unexpected. Performance differences between the static and motion conditions, and possibly between the NRS and RS motion conditions were expected, due to the 40–50% reduction in roll motion in the RS condition; however, this did not happen. The four-choice reaction time task and the critical tracking task were specifically used to approximate, respectively, the digit keying and tracking tasks used by McLeod et al. [1]. The present heave displacements of 12.5 ft (3.83 m) for NRS and 10.0 ft (3.06) for RS were greater than the 8.2 ft (2.51 m) found by McLeod et al. The present g level was less than 0.1 g; root mean square acceleration for McLeod et al. was 0.024 g. The present dominant range of frequencies was 0.06 to 0.2 Hz; it was 0.1 to 0.3 Hz for McLeod et al. The performance decrements obtained by McLeod et al. under relatively low g conditions disagree somewhat with findings by Jex et al. [2], who used a three-degree-of-freedom motion generator and found that motion conditions of 0.2 to 2.0 Hz at 0.5 to 1.0 g produced biodynamic interference in motor tasks, one of which was a critical tracking task. However, McLeod et al. [1] noted that their simulator introduced some "jolts" — brief periods of relatively high acceleration — into the movement. Their follow-up analysis to determine if their performance decrements were due to the "jolts" rather than the motion, indicated that tracking acquisition times were significantly increased due to the jolts; however, tracking errors were not affected. The jolts were reflected in a figure presented by McLeod et al. in which the plotted output acceleration showed numerous jagged components that did not correspond with the input displacement. The calibration of input signals and output movement in the NAVBIODYNLAB SMS was meticulously carried out to produce smooth, continuous movement with no jolts. Possibly the smooth and continuous motion encountered during both NRS and RS tests resulted in the lack of motion effects on performance in the present study.

In the McLeod et al. study, the subjects performed a pursuit tracking task with the forearm supported by arm restraints. Generally, better performance occurs with pursuit tracking tasks, since it is possible to predict target movement and keep the cursor on the target. Since the error from center is the signal to be tracked, errorless performance is possible only during pursuit tracking tasks, not during compensatory tracking tasks. At the beginning of the 7-sec trial reported by McLeod et al., the target and cursor began in random positions with the target inside a central area and the cursor outside this area. In the present study, the compensatory tracking task lasted 4 min per trial. During the 1-hr motion exposure, the 11 subjects received six 4-min trials at approximately 10 min intervals, whereas in the experiments of McLeod et al., ten subjects received 50 7-sec trials at intervals of 20–30 sec during the 22-min motion exposure. The NAVBIODYNLAB subjects performed the tracking task using either two or three fingers and with wrist and forearm supported on the response panel and console but not restrained. McLeod et al. used an arm restraint to support the forearm. Possibly the use of a "restrained" wrist *might* contribute to motion effects more than a "supported" wrist.

During the memory and search task, subjects rested wrist and forearm on the console and maintained the index and middle fingers in position over the two response buttons. During the four-choice reaction time task, subjects rested the forearm and wrist on the response panel and console while lightly resting the index finger in the middle of the four response keys. Thus in all the performance tasks subjects responded with wrist and forearm supported.

Neither motion condition produced significant motion sickness increases above baseline level. Possibly the similarity of performance was due to the lack of motion sickness experienced by the subjects during both motion conditions. Perhaps a "no task" ride might have produced motion sickness due to a diminution of focus of attention. Wiker et al. [2] reported results from numerous studies which showed that motion sickness, except during the act of vomiting, failed to degrade performance in tasks that included opening a combination lock, arithmetic computation, dial setting, card sorting, dart throwing, ball tossing, and the Whipple Steadiness Test. McLeod et al. [1] obtained subjective judgments for the sensations of well being, dizziness, sweating, headache, stomach awareness, salivation, and blurred vision. Only one symptom, general well being, showed a significant decline. McLeod et al. [1] concluded that the performance changes they noted were not due primarily to nausea, since the performance degradation from the no-motion to the motion condition remained stable during the motion test period.

Figures 4 and 6 suggest that the tracking task performance did not reach asymptote during the baseline training sessions. During the six days of training, subjects performed the tracking task for a total of 144 min (6 days, 6 times per day, 4 min per session). Bittner et al. [14] reported 100 min as the recommended time to obtain stability in the critical tracking task, but this was not the experience here.

The results indicated that subjects were indeed paying attention to the motion conditions. They accurately judged the amount of motion they were experiencing (see Figure 11). The NRS motion condition was judged greater than RS, which were judged greater than NRS-Post and RS-Post. These were judged greater than the baseline static conditions B-3 and B-5. Interestingly, subjects judged the NRS-Post and RS-Post to exhibit greater motion than B-3 and B-5. Possibly this was due to some motion aftereffect, since both NRS-Post and RS-Post were stationary.

CONCLUSIONS AND RECOMMENDATIONS

1. Subject performance on critical tracking, visual memory and search, and four-choice reaction time tasks was not affected by roll stabilized motion compared to non-roll stabilized motion, given smooth, continuous motion conditions. Future research should include more complex performance tasks that more closely approximate real-world Navy shipboard tasks.
2. Subjects reported no differences in motion sickness due to non-roll stabilized versus roll stabilized motion.
3. Subjects accurately judged the non-roll stabilized motion condition to be greater than the roll stabilized motion.
4. Future research is needed to determine which motion parameters produce the greatest performance decrement. In particular, are jolts — short durations of rapid acceleration — the critical motion parameter that causes performance degradation?
5. Additional studies should investigate the effects on performance of "restrained" versus "supported" wrists. Perhaps a restrained wrist interacts with motion and degrades performance on certain tasks, such as tracking, relative to a supported wrist.

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